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TECHNOLOGY UTILIZATION NOTES

Technology Utilization Division

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SELECTED WELDING TECHNIQUES, PART II

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SELECTED WELDING TECHNIQUES, PART II

From
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D. C. *July 1964*

NOTICE

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FOREWORD

THE Administrator of the National Aeronautics and Space Administration has established a technology utilization program for "the rapid dissemination of information . . . on technological developments . . . which appear to be useful for general industrial application." From a variety of sources, including NASA Research Centers and NASA contractors, space-related technology is collected and screened; and that which has potential industrial use is made generally available. Information from the Nation's space program is thus made available to American industry, including the latest developments in materials, processes, products, techniques, management systems, and analytical and design procedures.

This publication outlines some of the more recent and interesting welding technological developments. Although the basic welding processes involved are not entirely new, their improvement, modification, and use as an integrated whole are described briefly for possible industrial application. The welding tools and techniques described here have been selected from among those employed in the welding of aluminum sheet and plate at NASA's George C. Marshall Space Flight Center.

This report has been prepared as a cooperative effort between the Manufacturing Research and Technology Division and the Manufacturing Development Division, Manufacturing Engineering Laboratory, George C. Marshall Space Flight Center, Huntsville, Alabama.

The Director, Technology Utilization Division
National Aeronautics and Space Administration

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Conventional Weld Joints Versus Butt Joints in 1-inch Aluminum Plate

Significant Advantages Realized From New Method Which Utilizes Butt Joints

Because of the large size of the Saturn V first stage booster, aluminum alloy plate in thicknesses up to 1 inch is required in its construction. The conventional method of welding 1-inch aluminum plate requires that plate edges be prepared by machining either to a single-vee or a double-vee configuration, and carefully fitted together. The joining process requires the addition of filler metal to completely replace all the metal removed during edge preparation. The time, manpower, and facilities required first to remove metal, and then to replace an equal volume of metal by welding, make the conventional method a costly operation as well as one which introduces an extra degree of distortion into each weld.

Recognizing the need for improving the conventional method of welding 1-inch plate, NASA engineers developed a new method which allows 1-inch 2219–T87 aluminum alloy plates to be joined in a faster, less expensive manner. The new method utilizes a square butt joint and the gas tungsten-arc process for welding in all positions.

By this method, edges of each plate are machined smooth and square with the plate sides, thus requiring removal of only a minimum of metal. Smooth, parallel plate edges are then easily fitted together to form a square butt joint, leaving very little or no gap opening and a minimum of misalinement between the plates (fig. 1). Alinement of the plate edges is maintained by tack welding or by use of specially designed jigging clamps. The plates are then joined, with the addition of little or no external filler metal, by making one pass with a gas tungsten-arc welding torch along each side of the square butt joint (fig. 2). The technique requires precision controlled machine settings that will assure a minimum of ⅛-inch tie-in between the roots of the two beads formed during the first and second weld passes.

Welds made by this new method have mechanical and metallurgical properties equal to, or better than, those of welds made in the conventional manner. Angular distortion in these welds averages less than 1 degree. Because of

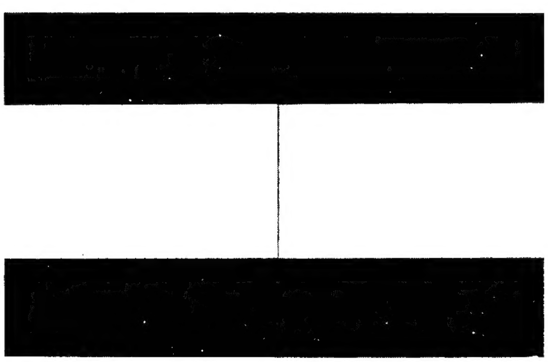

Figure 1.—Square-butt joint preparation and fitup for welding 1-inch aluminum plate.

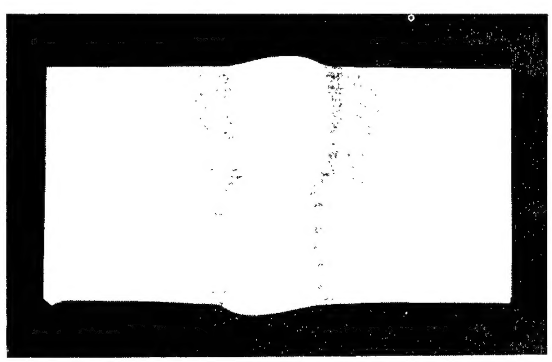

Figure 2.—Completed square-butt weld in 1-inch aluminum plate.

the smaller number of welding passes required in this method, X-ray quality of welds is much better than that of conventional, multiple-pass welds. In addition to the improved weld characteristics mentioned, the following significant advantages result from the use of this improved welding method.

(1) Less machine time is required for plate edge preparation.

(2) Less fitup time is required because of the wider abutting plate edges.

(3) Less welding time is needed because only a single pass is required on each side of the weld.

(4) Practically all costs of external filler metal are eliminated.

The only disadvantage of this welding method is the fact that no adequate nondestructive means has yet been devised whereby the tie-in between the weld bead roots formed during the two welding passes can be reliably examined or measured. Consequently, process control techniques used during the actual welding operation have been developed to insure weld product reliability.

Special Weld Joint Preparation

Continuous Welding of Large Aluminum Tank Segments Having Varying Material Thickness by the Gas Tungsten-Arc (TIG) Process Is Described

In welding large cylindrical aluminum tank segments, each of which is made from material having thicknesses that vary from 0.40 to 1.00 inch within the same weld joint and 10 feet or more in height, the problems of vertical welding technique, groove or joint configuration, and appropriate tooling to minimize distortion are encountered. All of these problems were encountered in the fabrication of the 33-foot diameter fuel and liquid oxygen tanks for the

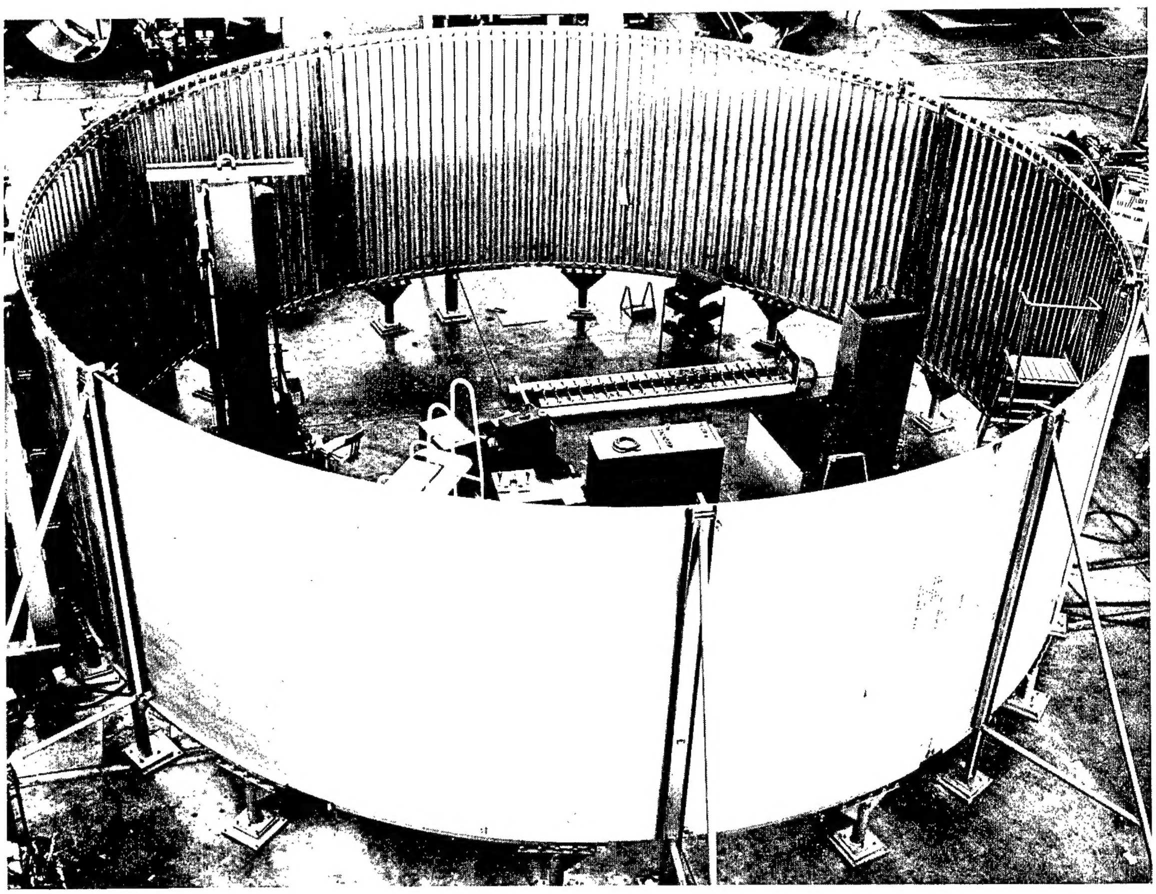

Figure 3.—Four cylindrical skin segments (welded in vertical position) for the 33-foot diameter S–IC Saturn LOX and fuel tanks.

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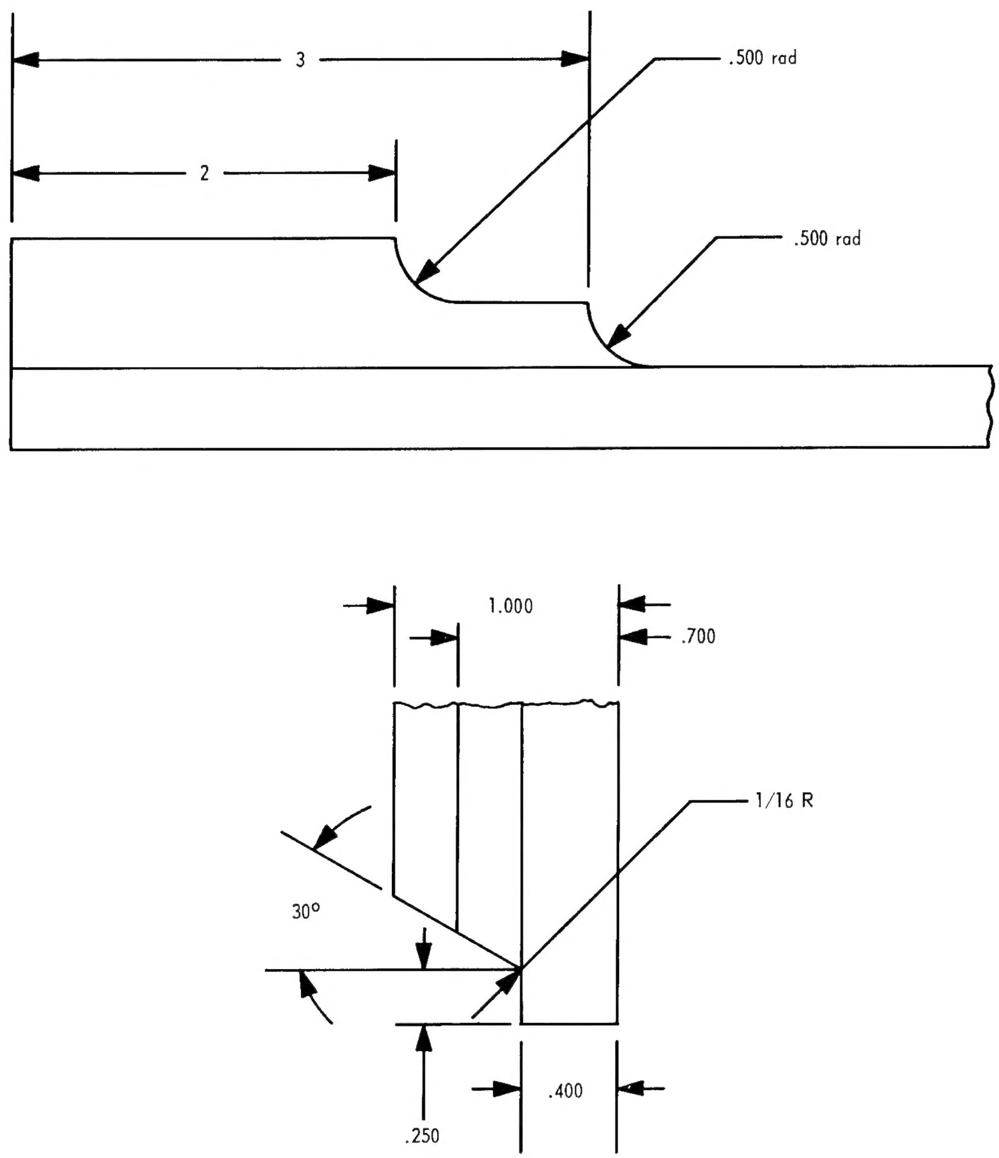


Figure 4.—Special weld joint configuration for vertical welding of LOX and fuel tank cylindrical skin segments.

S–IC booster stage of the Saturn V space launch vehicle. Each cylindrical segment of these 43- to 64-foot-long tanks is composed of four curved panels which, when joined by welding using the DCSP gas tungsten-arc (TIG) process, form the 10-foot-long segment of the tank (fig. 3).

Test panels, 10 feet long and approximately 20 inches in width, were machined to simulate the edge configuration of the full-size panels to be used in the S–IC tanks. Material thickness along the 10-foot joint between adjacent panels varied from 0.400 inch for the lower 9-foot 9-inch area to 1.000 inch in the top 3-inch area. The major welding problem was encountered in the top 3 inches because of the change in thickness from 0.400 inch to 1.000 inch. In order to allow a full-penetration continuous vertical weld in a single pass from bottom to top, a 60-degree included angle groove with a 0.400-inch land, as shown in figure 4, was machined in the top 3 inches of each panel, with a square groove edge preparation being used for the balance of the panel length. Upon completion of the single-pass weld in the 10 feet of 0.400-inch material, the remainder of the machined groove in the top 3 inches was filled by several manual passes, using the gas tungsten-arc (TIG) process. The multiple-pass manual welding required in this area resulted in excessive distortion (approximately 8 degrees). To minimize this undesirable condition, special tooling, consisting of heavy holddown bars, was used to hold the panels

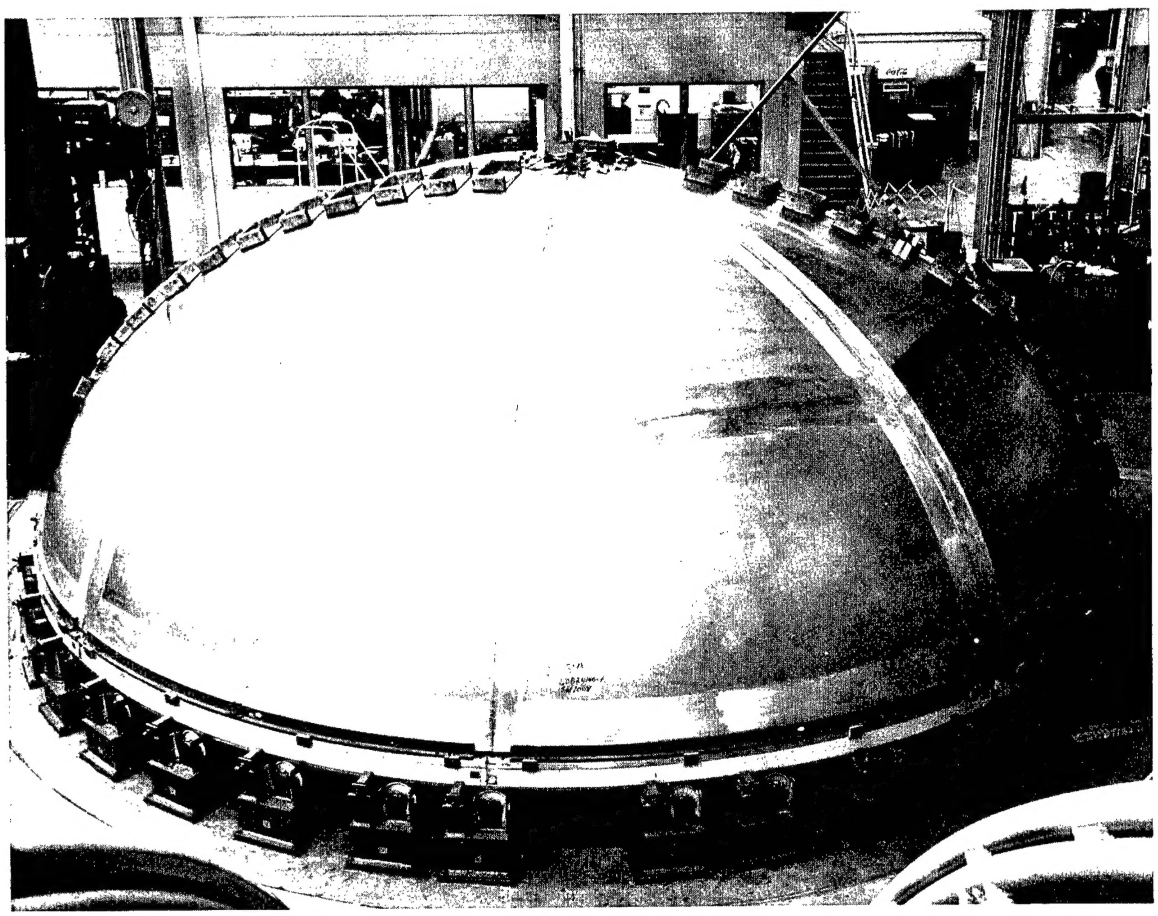
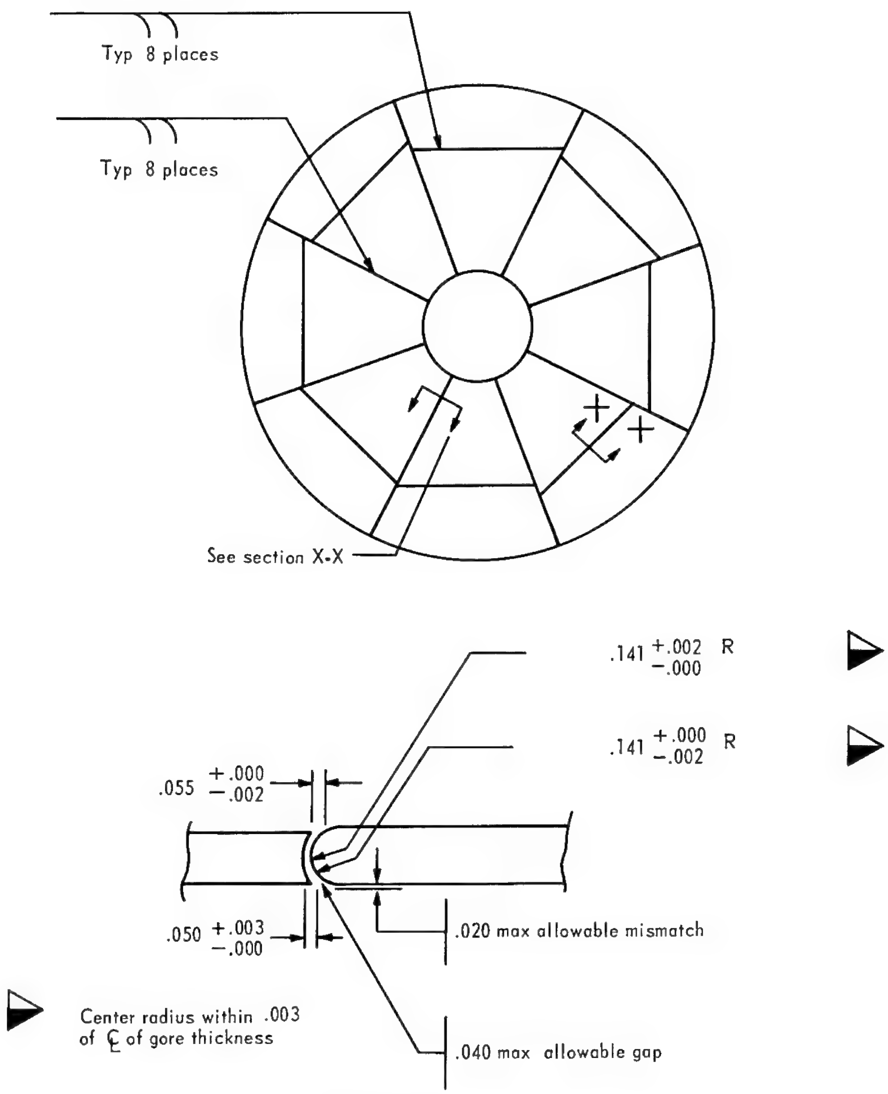


Figure 5.—Thirty-three-foot diameter welded bulkhead showing apex gore and base gore horizontal welds and meridian welds.



Section 'X–X'

Typical for all apex to base gore and meridian gore welds

***Figure 6.*—Special weld groove configuration for welding LOX and fuel tank bulkheads.**

rigidly in place during the operation. This procedure effectively kept distortion to a maximum of 2 degrees.

In welding the bulkheads for the 33-foot diameter fuel and LOX tanks, 16 separate sections, consisting of 8 apex gore segments and 8 base gore segments, were first welded horizontally. Because of the buckling of the 0.359-inch plates from the heat of welding, vacuum chucks used as hold-down clamps would not maintain the complex curvature of these sections (fig. 5) in perfect alinement. Mating edges of gore sections would climb either over or under each other; thus, it was impossible to maintain the intricate curvature, or radius, during welding. In order to eliminate this problem, a special weld joint, shown in figure 6, was designed. This "tongue-and-groove" joint locked together the complex curvature mating edges of the apex and base gore segments so that no further difficulty was experienced in making the weldment. The meridian welds, gore-to-gore sections, were completed in the same manner.

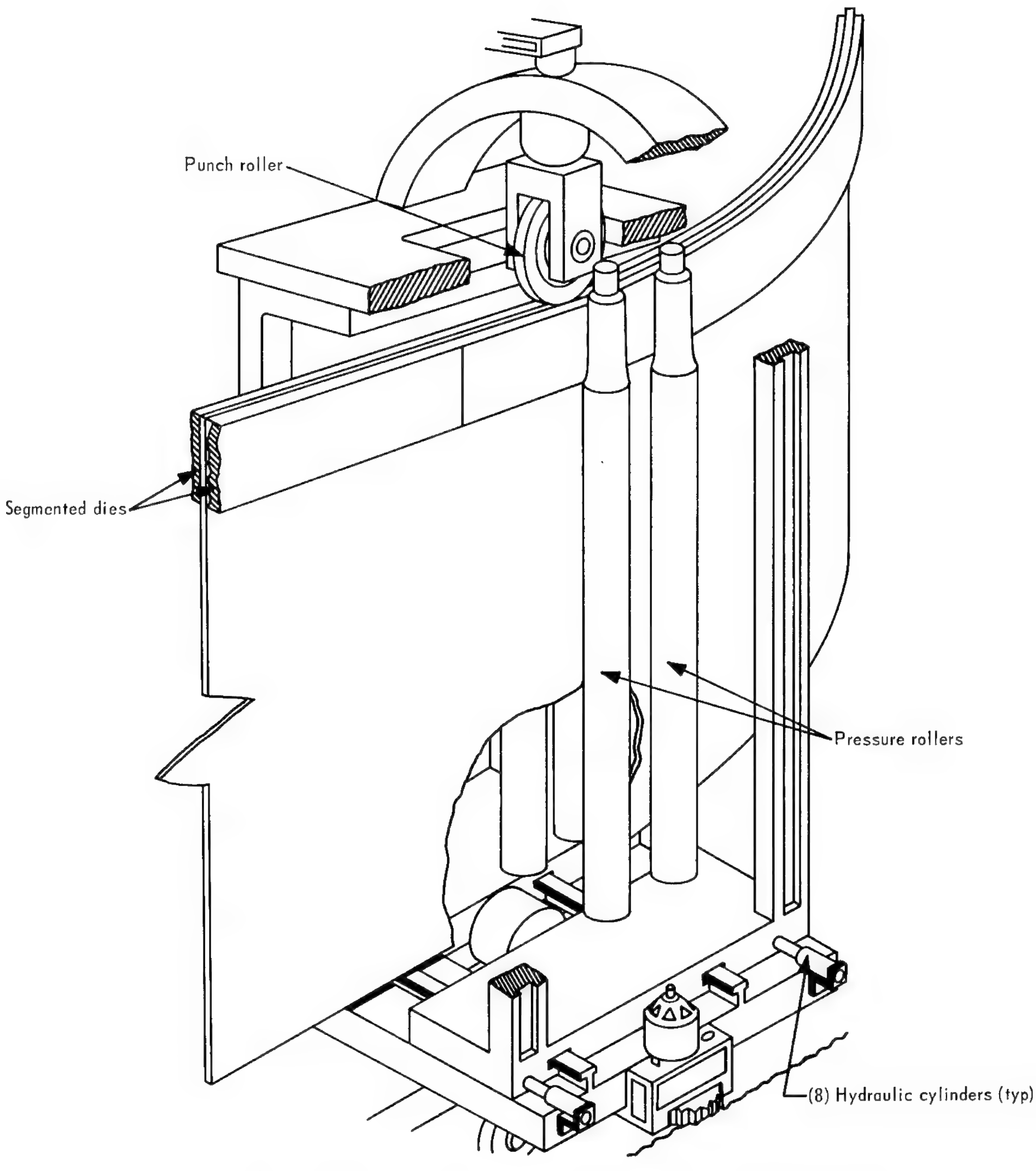


Figure 7.—**Tooling concept for metal edge upsetting of aluminum alloy cylindrical skin sections.**

Upset Metal Edges for Increased Weld Joint Strength

Unique Process Allows Material Thickness Selection Based on Stress Requirements Only

In the fusion welding of either heat treatable or non-heat treatable aluminum alloy sheet or plate stock, the heat of the welding arc adversely affects the hardness of the parent metal immediately adjacent to the weld. In this area, commonly referred to as the Heat Affected Zone (HAZ), a majority of the weld failures occurs. However, increasing the material thickness in this area prior to welding will compensate for the lower specific strengths obtained, resulting in higher weld joint efficiencies.

The need to improve weld joint quality prompted the development of the metal edge upset process by Marshall Space Flight Center Manufacturing Engineering Laboratory personnel. However, the technique was developed primarily for use with flat sheet or strip stock. Consequently, the introduction of the internally ribbed skin segments for large missile components prevented the metal edge upset process from being utilized as a production method.

The upsetting process, to obtain increased metal edge thickness, uses retaining dies, rigidly positioned on each side of the part, at the edge where increased thickness is required. Hydraulic pressure of sufficient force is then applied on the butt edge of the material to upset or force the metal to flow into the die cavities. The contour of the die cavities conforms to the upset pattern or edge thickness required on the material.

The use of a narrow form roller as a medium for applying the upsetting pressure will, in addition, complete the required weld groove of the metal edge.

Since the compressive strengths of the different alloys vary considerably, it is necessary that the force requirements be correlated to the particular alloy under consideration, thickness of the material, and the upset pattern required.

Figure 7 illustrates a tooling concept for the metal edge upsetting of an aluminum alloy cylindrical section. The part as shown is positioned vertically on a movable carriage directed by a circular track.

Segmented circular dies are located on each side of the part, at the edge to be upset. The upsetting hydraulic force is transmitted downward, through the medium of a form roll traveling longitudinally on the butt edge. Opposition to the downward upset force originates from hydraulic cylinders, and this force is then transmitted to the dies through the medium of pressure rolls and carriage adjustments.

Figure 8 illustrates a typical upset weld joint in aluminum alloy plate stock. The 25-percent increase in edge thickness of sufficient width to include the heat affected zone resulted in weld joint strength equal to that of the parent metal, or 100-percent joint efficiency.

The process is unique because it eliminates machining operations to effect weld joint fitup and groove configuration. In addition, material thickness selections can be based upon stress requirements only. The technique eliminates the necessity of selecting materials in excess of thickness as dictated by stress requirements, and (in the interest of weight reduction) of milling out, by mechanical or chemical means, the non-weld areas to stress requirement thickness.

The principle can also be used for the squaring of sheet stock or the sizing of cylinders. In addition, the upset pattern of the metal edge can be any configuration—radial, flat, angular, or as required for any specific purpose.

Dim. A	B	C	D
Parent metal	1.25A	$\frac{W}{2}+.125$	C+3/8"

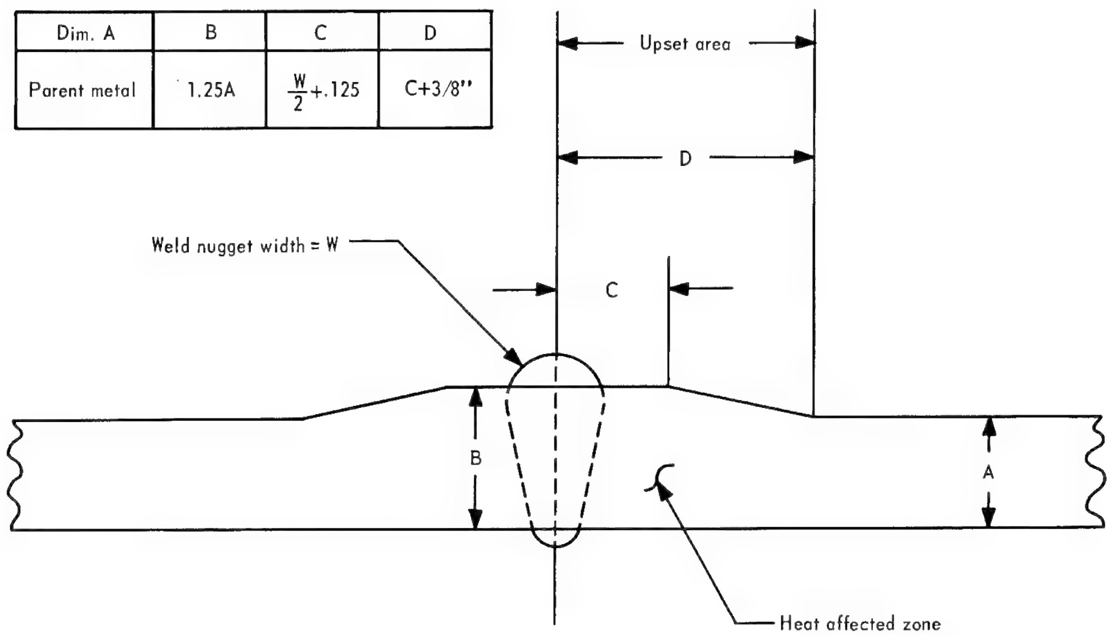


***Figure 8.*—Typical upset weld joint in aluminum alloy plate stock.**

Out-of-Position Welding of Heavy Gage Aluminum Alloy in Space Vehicle Applications

TIG Welding Process Using Square Butt Joint Proved Most Satisfactory for All Positions

The introduction of the Saturn V vehicle has required the use of heavy gage, high strength aluminum alloys. Because of its favorable strength-to-weight ratio, it was decided that the relatively new alloy, 2219 aluminum, would be used in material thicknesses from 0.224 inch through 1.000 inch. Also, because of the massiveness of this giant space booster vehicle, the conventional methods of weld fabrication that had been successfully used on the earlier vehicles were no longer practical. This fact resulted in the introduction of the concept of "vertical assembly" and out-of-position weld fabrication. (See fig. 9.) While each of these changes presented problems, one of the most difficult to solve involved the plate material thicknesses that

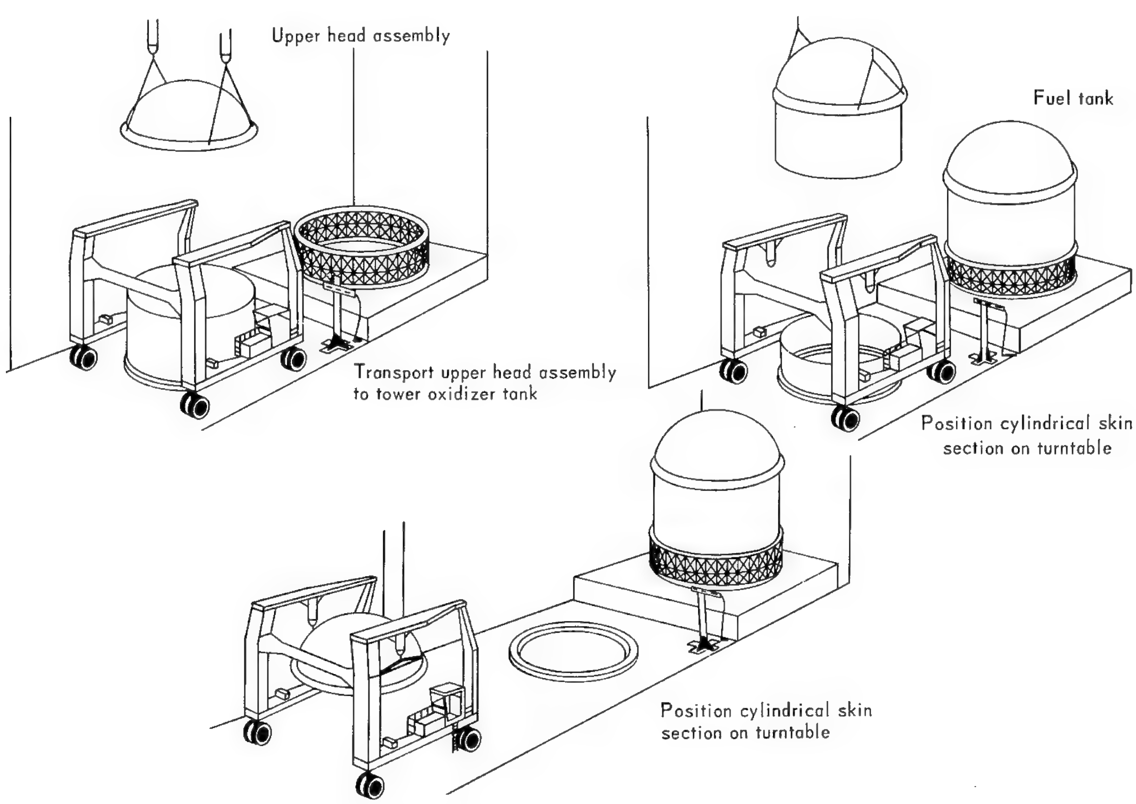


***Figure 9.*—Weld tank assembly for the S–IC vehicle.**

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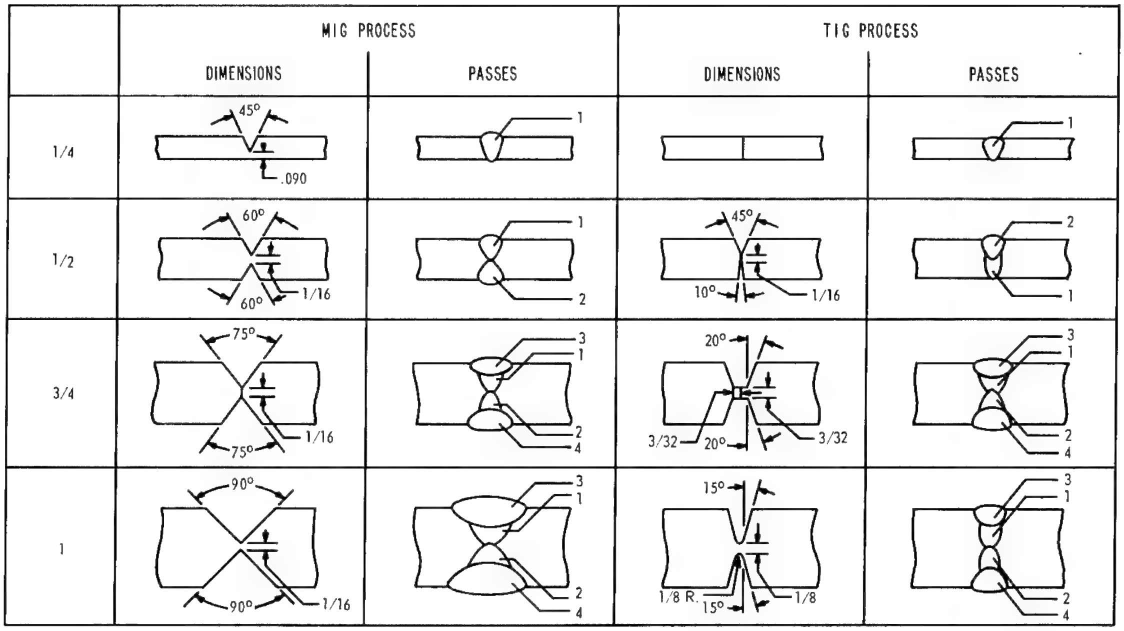


Figure 10.—**Weld joint geometries.**

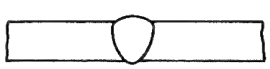
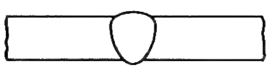
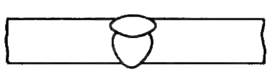
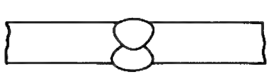
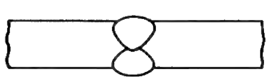
THICKNESS	JOINT GEOMETRY	AMPERAGE	VOLTAGE	TRAVEL (IPM)	YIELD STRENGTH (PSI)	ULTIMATE STRENGTH (PSI)	ELONG. % 2"
0.224		220	12	10	24,000	41,000	4.4
0.400		225	12	6	22,500	38,000	3.5
0.500		290	12	7	23,000	39,000	4.0
0.700		420	11.5	7	24,500	43,000	5.5
1.000		450	12	4	22,000	41,000	5.5

Figure 11.—**Typical TIG welding data to be used on S–IC vehicle.**

had to be welded to meet the high quality standards required for space vehicles.

In the early stages of development, almost every conceivable weld joint geometry was investigated. (See fig. 10.) Both the TIG and the MIG processes were evaluated in the flat, vertical, and horizontal positions of welding to insure that the best possible welding procedures, techniques, and equipment would be available for the S–IC vehicle in order to produce the highly reliable structure that is needed.

In evaluating the various welding joint geometries and techniques for out-of-position welding, the following basic requirements were used as guide lines:

1. High visual and X-ray quality.
2. Maximum mechanical properties.
3. Ease of weld joint preparation.
4. Ease of weld joint fitup.
5. Number of weld passes.
6. Welding from one side vs two sides.

After extensive investigation, it was concluded that the TIG welding process, utilizing a square butt joint, produced the most satisfactory results for all positions of welding. Figure 11 shows typical TIG welding data that are used on the S–IC vehicle. The square butt joint requires a minimum of machining and is most easily alined. The TIG process, utilizing the "buried-arc" technique, produces deep penetration welds requiring a minimum number of weld passes. The "buried-arc" technique, illustrated in figure 12, consists of placing the end of the tungsten electrode physically below the surface of the plate material being welded. It is particularly effective when welding plate material 0.750-inch thick and greater. The TIG process has also been found to produce welds of consistently higher quality than those made with the MIG process. In material thicknesses up to 0.400 inch, the welding is accomplished using a single pass from one side without a backup bar. In material thicknesses between 0.400 inch and 0.600 inch, two passes from the same side are used. For material of greater thicknesses, welding is accomplished by depositing a single pass from each side.

It must be pointed out that the TIG process with the square butt weld joint is the method currently used for joining plate thicknesses of aluminum for space vehicle applications. However, a continued effort is being made to further improve and refine all methods of welding, and this could dictate the use of other welding processes and techniques in some of the future vehicles.

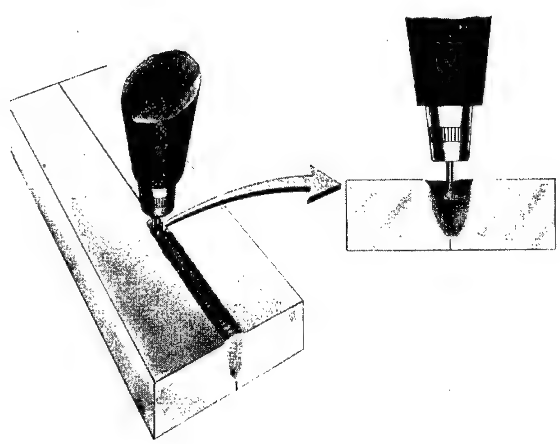


Figure 12.—TIG "buried arc" welding technique.

Electron Beam Welding

New Fusion Welding Process More Efficient Than Any Other Available Today

The demands of an explosively advancing technology for weldments of exotic metals and alloys have required investigation of new welding techniques and processes capable of producing these weldments. One of the more recently developed welding methods is known as electron beam welding. It is a process that produces precision fusion welds with greater efficiency than any other fusion welding process available today. Since the process requires vacuum for electron emission, environmental contaminants are virtually non-existent, resulting in metal purity far greater than that of the best inert gas-shielded process presently known.

The electron beam process utilizes the heating effect of a concentrated beam of electrons accelerated to about $1/10$ the speed of light impinging on the weldment. This kinetic energy does not appear as heat until the electrons hit the work itself; the beam is invisible and only the results can be seen. When the local heat input is greater than the heat transfer capacity of the metal surrounding the point at which the beam strikes, the metal melts, and fusion takes place. Since no appreciable force is exerted on the pool by the beam, there is little tendency to blow through, and only a small tendency to form craters at the end of a weld. By progression

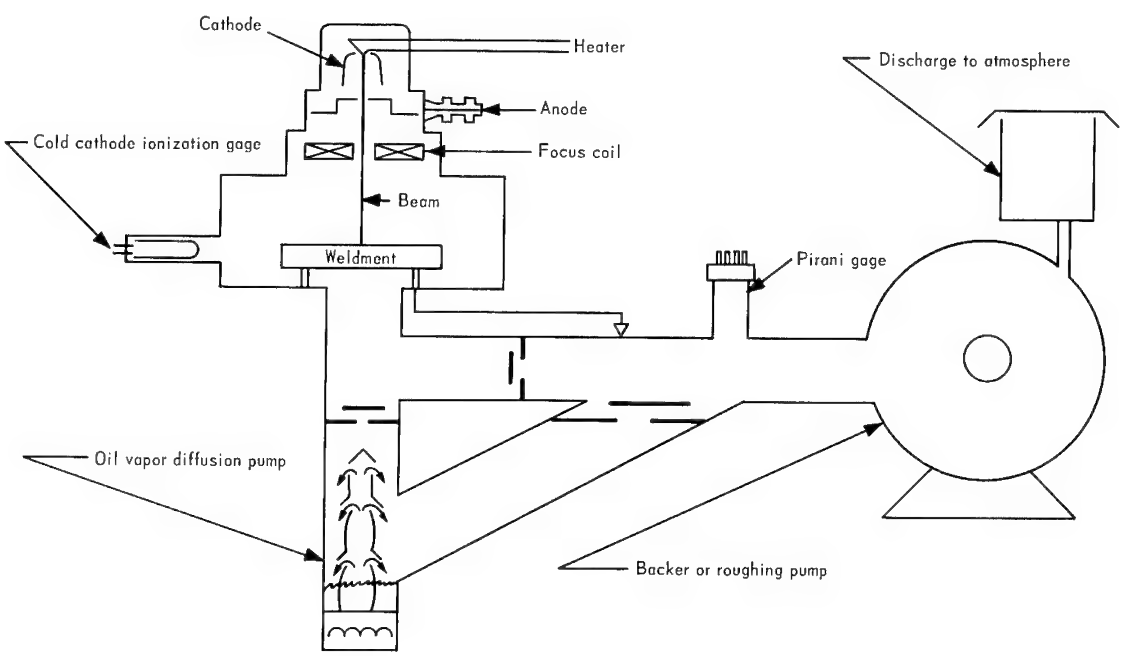


***Figure 13.*—Basic electron beam welding system.**

along the seam, a continuous weld can be made. The fused area is extremely narrow, having a ratio of depth to width of over 20 to 1. Wide ranges of accelerating voltages are possible and welds may vary from very slight to very heavy penetration. Also, because the beam can be focused to produce heat input to a very concentrated area, spot diameters of less than 0.01 inch are easily obtainable.

The process is particularly applicable in the joining of refractory metals, extremely light gages such as foil, extremely heavy gages, or in the joining of very thin material to very heavy material.

In addition to welding by fusion, the principle can be used for melting, grain refining, stress relieving, metalizing, vacuum brazing, and such. Containers enclosed by electron beam welding retain an internal vacuum when removed from the welding chamber.

Figure 13 shows the basic essentials for a beam welding system. The vacuum apparatus consists of a welding chamber equipped with viewing ports and vacuum sealed doors. This chamber, for efficient operation, requires a vacuum pressure of one ten-millionth of an atmosphere or 0.1 micron of mercury. In such a vacuum, gaseous impurities total less than 1 part per million, as opposed to at least 20 parts per million as the best level attainable with inert gas shielded methods. Mechanical roughing pumps of any design, and having the required capabilities, may be used to draw the pressure down to approximately 100 microns. At this point, the oil vapor

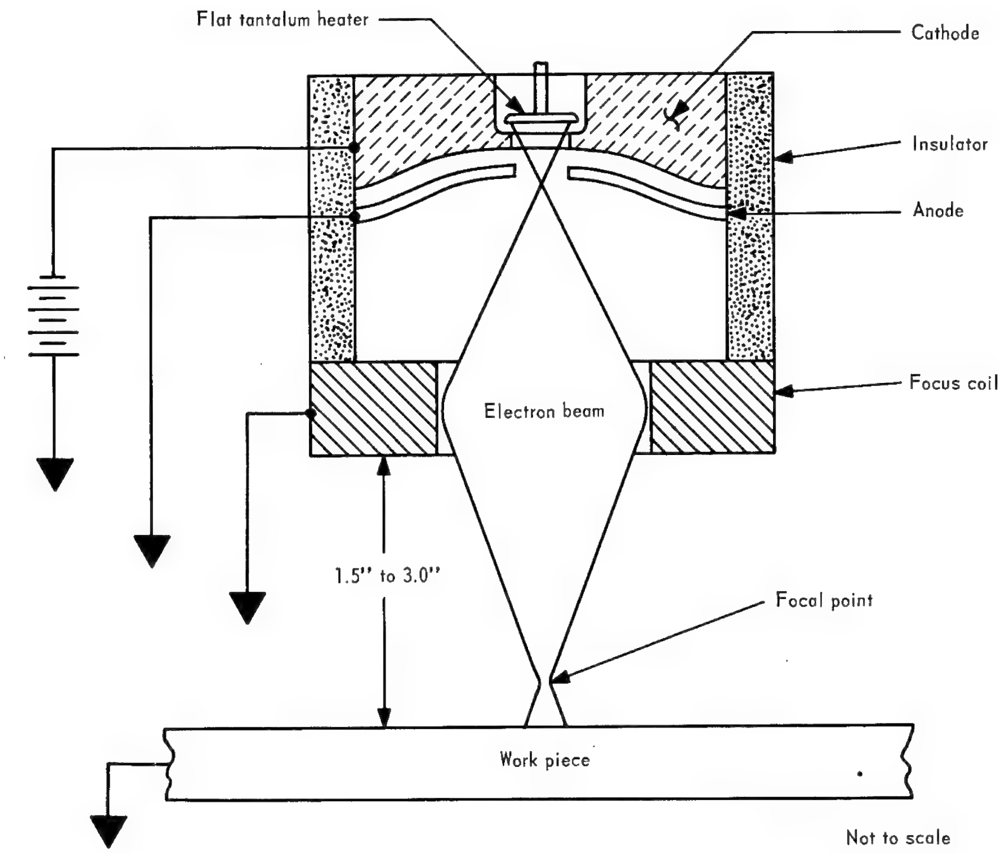


***Figure 14.*—30-KW Pierce-type electron gun.**

diffusion pump can be valved into the circuit. The two pumps in series then pull the system down to the desired high-vacuum range.

The electron beam gun consists of a heater, cathode, anode, and focus coil. Cathode elements, such as tungsten and tantalum, are emitters of electrons in a vacuum when heated; this stream of electrons is accelerated by the anode and focused upon the object to be welded.

Accelerating voltages may be as low as a few kilovolts or as high as 100 or more kilovolts. The low voltage apparatus produces a minimum focused spot size several times greater in diameter than that obtained with high voltage equipment. Consequently, where an exceptionally high depth-to-width ratio is needed in the penetration pattern, high voltage apparatus may be necessary.

Figure 14 shows the 30-KW Pierce-type electron gun for use in welding the 2.3-inch thick Saturn V "Y" ring with a single weld pass, using a square butt joint. This gun, currently undergoing acceptance tests by Marshall Space Flight Center personnel, produces 1 ampere of current at 30,000 volts for a total power rating of 30 KW.

Gas Metal-Arc Welding Versus Electron Beam Welding

Procedure Developed Utilizing Superior Electron Beam Welding for Y-Ring Segments

The Y-ring of the Saturn C–5 first stage booster, which is joined by welding to the bulkhead, the skirt, and the cylinder section, is 33 feet in diameter, 26 inches in height, and 2⅜ inches in maximum thickness. Original manufacturing procedures for these rings required that three 2219–T87 aluminum alloy billets, 34 feet long by 27 inches wide by 5 inches thick, be rolled into 120-degree segments of a circle, gas metal-arc welded to form a ring, and then machined to final Y-configuration and dimensions.

Double-U joint preparation of the segment ends requires three hours machining time for each ring.

Welding, using the gas metal-arc (MIG) process, requires 50 passes per side, or a total of 100 weld passes per joint, as shown by figure 15. At the welding rate of 4 inches per minute, approximately 32 hours welding time is required per ring. Cumulative welding time for the three joints in each ring, allowing time for weld interpass cooling, is 80 hours to deposit the required 300 cubic inches of filler metal in the double-U joints.

Verification of weld quality by X-ray is made after each two weld passes, thus requiring 50 X-ray exposures per joint or 150 per ring.

Normal heat distortion, weld defects, and the time-consuming processing steps just enumerated made it extremely desirable that the electron beam welding process, by which an energy concentration of 1,000,000 watts per square inch may be obtained, be studied and a method developed for using the process in joining Y-ring segments. As a result, Marshall Space Flight Center engineers, in cooperation with their contractors, have developed and refined fabrication techniques to utilize electron beam welding for joining Y-ring segments.

The process required that the joint to be welded and the source of the electron beam which provides the heat for welding be enclosed in the same hard vacuum chamber. Consequently, the size of the weldment had been restricted to that which could be properly fitted into the vacuum chamber.

Extremely large vacuum chambers make pumping to the desired high vacuum a tedious,

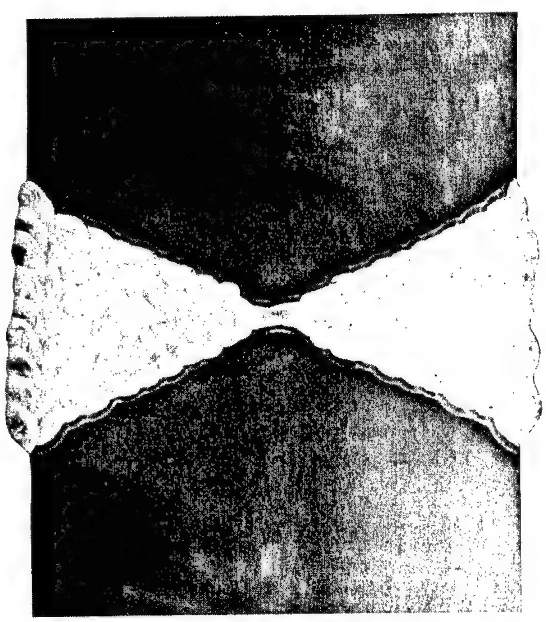


Figure 15.—**Completed double-U weld joint in 5-inch 2219–T81 aluminum alloy plate after approximately 50 passes on each side of joint.**

if not futile, task. Therefore, for this and other obvious reasons, it was impractical to enclose the entire Y-ring in a chamber.

As shown in figure 16, the vacuum chamber was made smaller than the part so that it does not enclose the entire ring, but only the local areas to be joined by the electron beam welding process.

Since the Y-ring constitutes a closed loop when the final weld has been made, it was necessary that the vacuum chamber be made removable. Accordingly, the chamber of the Y-ring electron beam welder is split into two sections. Hermetic sealing of the chamber sections up the Y-ring is accomplished by the use of O-rings and flat gaskets of rubber composition.

This procedure of enclosing only the joint area, of large weldments, in the vacuum chamber during electron beam welding permits much more effective control over the steady high vacuum required during the welding cycle. In addition, the smaller volume to be evacuated can be accomplished by relatively smaller vacuum pumps.

This principle can be used for the fusion welding, by the electron beam process, of large weldments of almost any configuration. The only limiting factor is that the vacuum chamber be of sufficient size to effectively enclose the joint area.

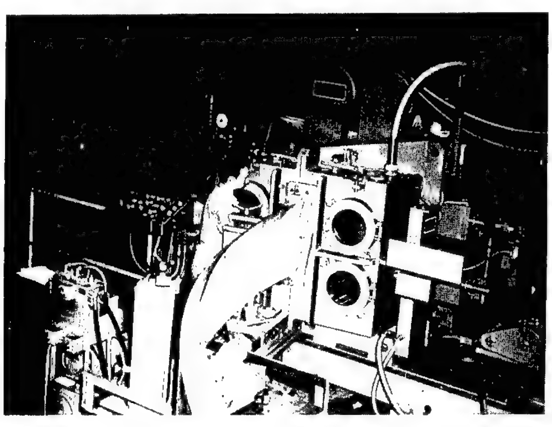


Figure 16.—**Saturn V Y-ring weld joint positioned in vacuum chamber prior to electron beam welding.**

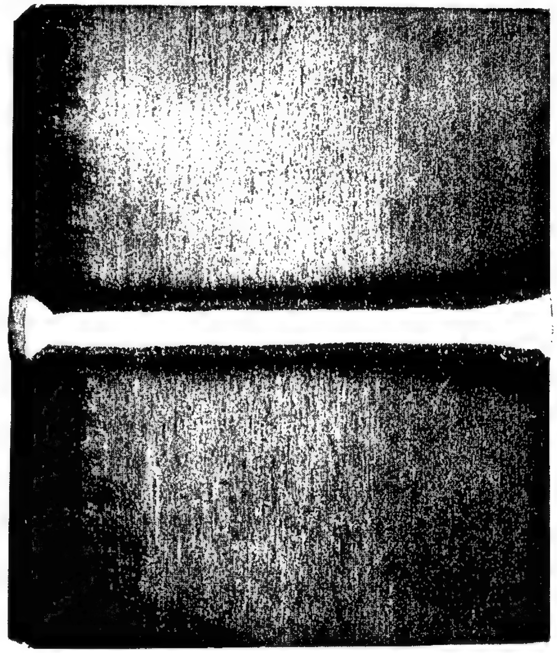


Figure 17.—**Completed single-pass electron beam weld in 2⅜-inch 2219–T87 aluminum alloy plate.**

The manufacturing procedure utilizing electron beam welding is to roll the 34-foot x 27-inch x 5-inch aluminum alloy billets into 120-degree segments, machine the segments to finished Y-contour and dimensions, prepare segment ends welding by machining to a smooth finish, and then join segments by electron beam welding (fig. 17). This procedure eliminates segment and double-U joint preparation and permits square butt welding. Complete joining is accomplished by a single weld pass at a speed of 30 inches per minute without the addition of filler metal. Nine X-ray exposures are required to verify the quality of the three welds in each ring.

Development of Improved Weld Filler Wire

Improvements in Aluminum Filler Wire Result From Specification Requirements

As a joining process, welding is subject to the influence of many variables. To obtain the high-quality welds required in space launch vehicles, these variables must be controlled to the greatest extent possible.

Aluminum alloy 2219, by virtue of the ease with which it may be fabricated and repaired, as well as its excellent mechanical properties, was selected for the S–IC stage of the Saturn V launch vehicle. This alloy had been previously welded successfully in thicknesses up to ¼-inch by several companies utilizing 2319 as the filler wire.

First attempts to produce launch vehicle quality welds in the greater metal thicknesses (¼ inch to 5 inches) required by Saturn V, however, proved to be extremely difficult. Some of the problems experienced were attributed to the 2319 weld filler wire used. These problems were:

1. Tendency for the wire to jam in the feed mechanism of mechanized weld equipment.
2. Unacceptable X-ray quality as a result of excessive weld porosity.
3. Poor reproducibility and reliability of welds.

The following reasons, singly or in various combinations, were used to explain the lack of acceptable quality in early welds:

1. Nonhomogeneous distribution of microstructural constituents within the wire.
2. Nonuniform hardness and strength of wire.
3. Nonuniform diameter of wire.
4. Poor, nonuniform wire surface quality and finish, e.g. laps, seams, slivers, or pitting.
5. Gouges, nicking, and galling of the wire surface.
6. Contamination of wire surfaces by oxidation and organic lubricants.
7. Poor wire winding or spooling techniques.
8. Inadequate packaging methods.

A program was initiated to examine each lot of incoming wire to check packaging, spooling, chemical analysis, mechanical properties, surface condition, and microstructure.

As a result of deficiencies observed during this program, a specification evolved which outlined minimum acceptance standards necessary for 2319 filler wire for use in space launch vehicles. This specification covered exact requirements for surface quality and finish, surface cleanliness, chemical analysis, microstructure, mechanical properties, diameter, winding or spooling,

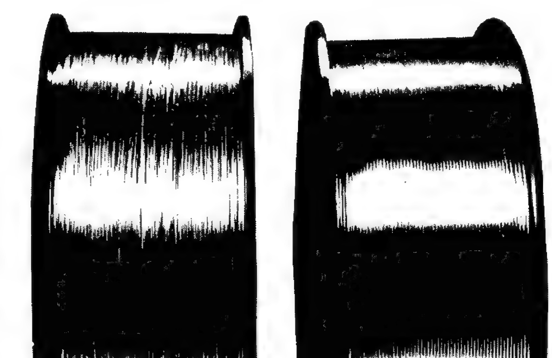


Figure 18.—**Comparison of acceptable and unacceptable welding wire winding methods.**

and packaging. While the requirements of this specification were more stringent than in any other previous aluminum filler wire specification, both NASA and industry felt that these requirements could be met.

To satisfy the requirements of this new specification, industry developed an improved, high-quality filler wire, better winding methods (fig. 18), and new packaging concepts (fig. 19). The improvements in all of these items did not occur overnight, but took months of hard work and close cooperation between NASA and industry.

The present Marshall Space Flight Center filler-wire acceptance process, M–ME–MPROC 700.1, is available as a model for use by those who are interested in producing space launch vehicle quality welds in aluminum alloys.

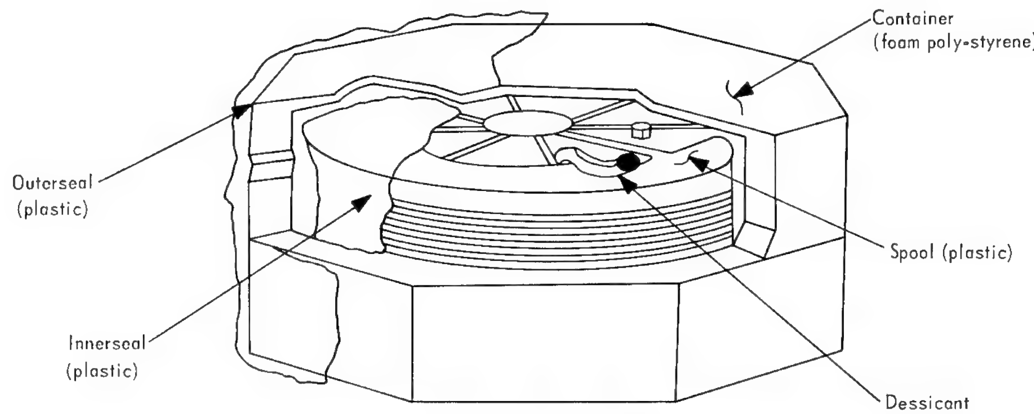


***Figure 19.*—New filler metal packaging method for high quality aluminum wire.**

Special Welding Nozzle Configuration

New System Effective in Removing Fumes, Vapors, and Particulate Matter

The maintenance of welding arc stability in an environment of excessive air currents is a problem which may be encountered in any of the arc welding processes. Effective removal of fumes generated during fusion welding operations presents additional problems. The toxic fumes emitted can be a health hazard, particularly in the fusion welding of such materials as galvanized steels and metals containing radioactive alloys or beryllium alloys. This problem becomes more acute in confined areas where shields set up to protect the welding area from air currents prevent the dissipation of welding fumes. Auxiliary exhaust systems may be used to remove fumes, but may also disrupt the controlled inert gas atmosphere protecting the molten metal.

Aerospace engineers of NASA, recognizing these problems, instituted a program to develop a welding nozzle which would eliminate fumes, vapors, and particulate matter from the welding area without adversely affecting the shielding gas atmosphere around the welding arc.

Figure 20 shows the original nozzle design concept for use with a mechanical MIG welding torch. This principle utilizes a vacuum pump to remove all toxic fumes, particulate matter, and other possible contaminants from the vicinity of the welding arc.

As developed, the special welding nozzle system consists of an Airco No. AM60–A welding torch to which is attached an inner, short conical jacket, and an outer, long conical jacket (fig. 21). The smaller diameter inner conical jacket serves to conduct shielding gas from inside the gun barrel down around the welding arc. The larger diameter outer conical jacket exhausts the mixture of fumes, vapors, shielding gas, and entrapped air from the area of the welding arc back up around the barrel of the welding gun and away into an exhaust system. The outer conical jacket has built into it a rectangular box extension which serves to extend the evacuation area lengthwise along an unwelded joint.

The exhaust suction up through the annular opening between the concentric inner and outer conical jacket and up through the box extension of the outer conical jacket is obtained by two separate exhaust systems, each of which is capable of producing a minimum of 3 inches of mercury under operating conditions. One of the exhaust systems is connected through a manifold to the outer conical jacket, while the second is connected directly to the box extension on the outer conical jacket.

Tests conducted during actual welding operations, using ½-inch thick type 2219–T87 aluminum alloy plate stock, revealed that the exhaust systems were effective in removing fumes, vapors, and particulate matter produced during welding, even when drafts of air at velocities up to 500 fpm (5–6 mph) were blown transversely or longitudinally with respect to the weld joint.

However, examinations of the fused joints obtained showed variations in the degree of weld quality. Early specimens were out of the range of acceptable standards. Later, a limited quantity of satisfactory welds was produced. These specimens had good weld bead appearance with

no undercutting. Mechanical properties were within the range of acceptable standards, and microscopic examination revealed only fine scattered porosity. This variation in the quality of the fused joints obtained is attributed to the extreme difficulty encountered in establishing and maintaining the precise degree of vacuum in the outer conical jacket, for a specific fusion welding atmosphere, during the operation.

Further developmental refinements, including more precise controls to readily establish an optimum degree of vacuum in the outer conical jacket, for any welding atmosphere, would result in more consistent and higher quality welds.

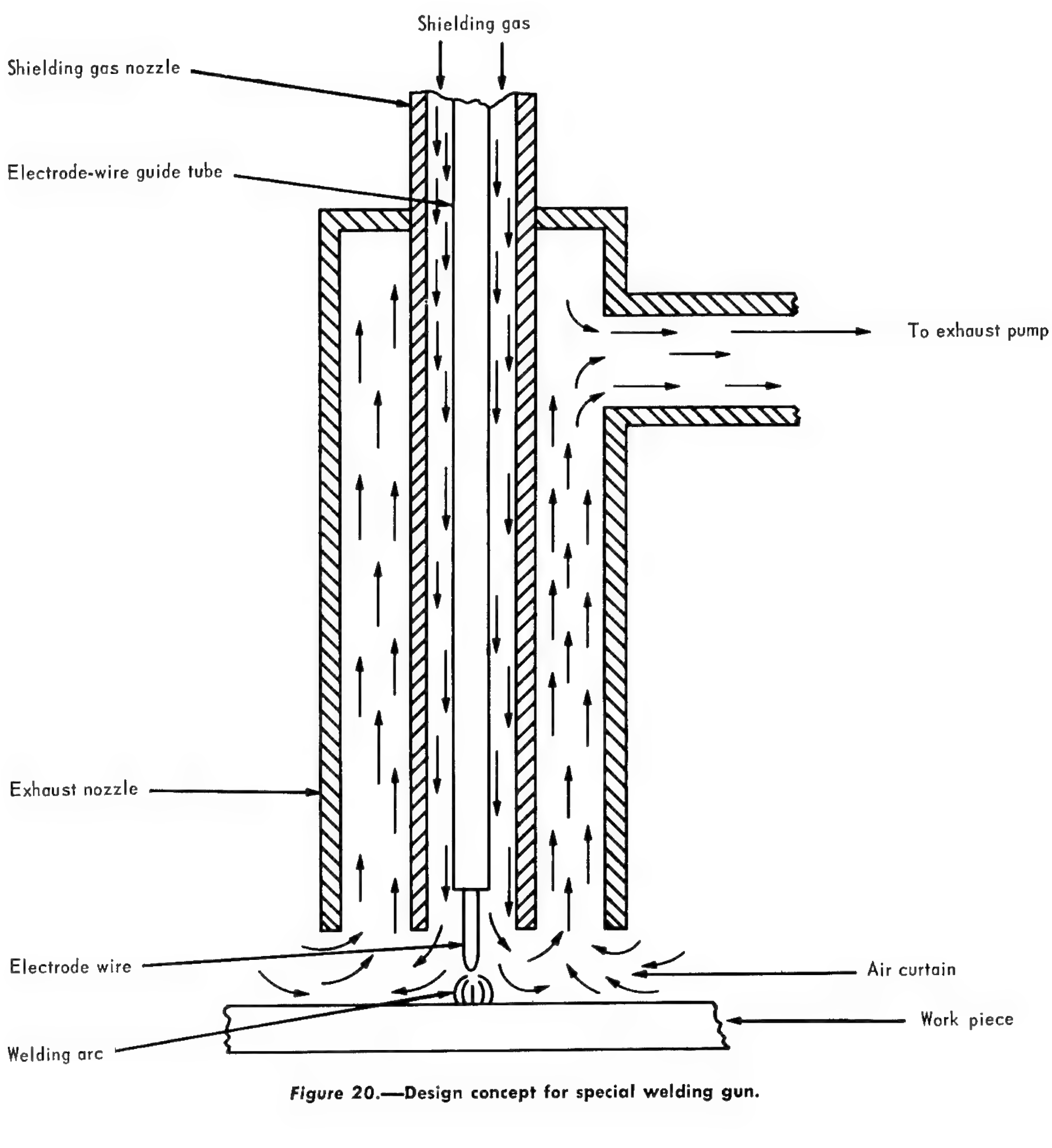


Figure 20.—**Design concept for special welding gun.**

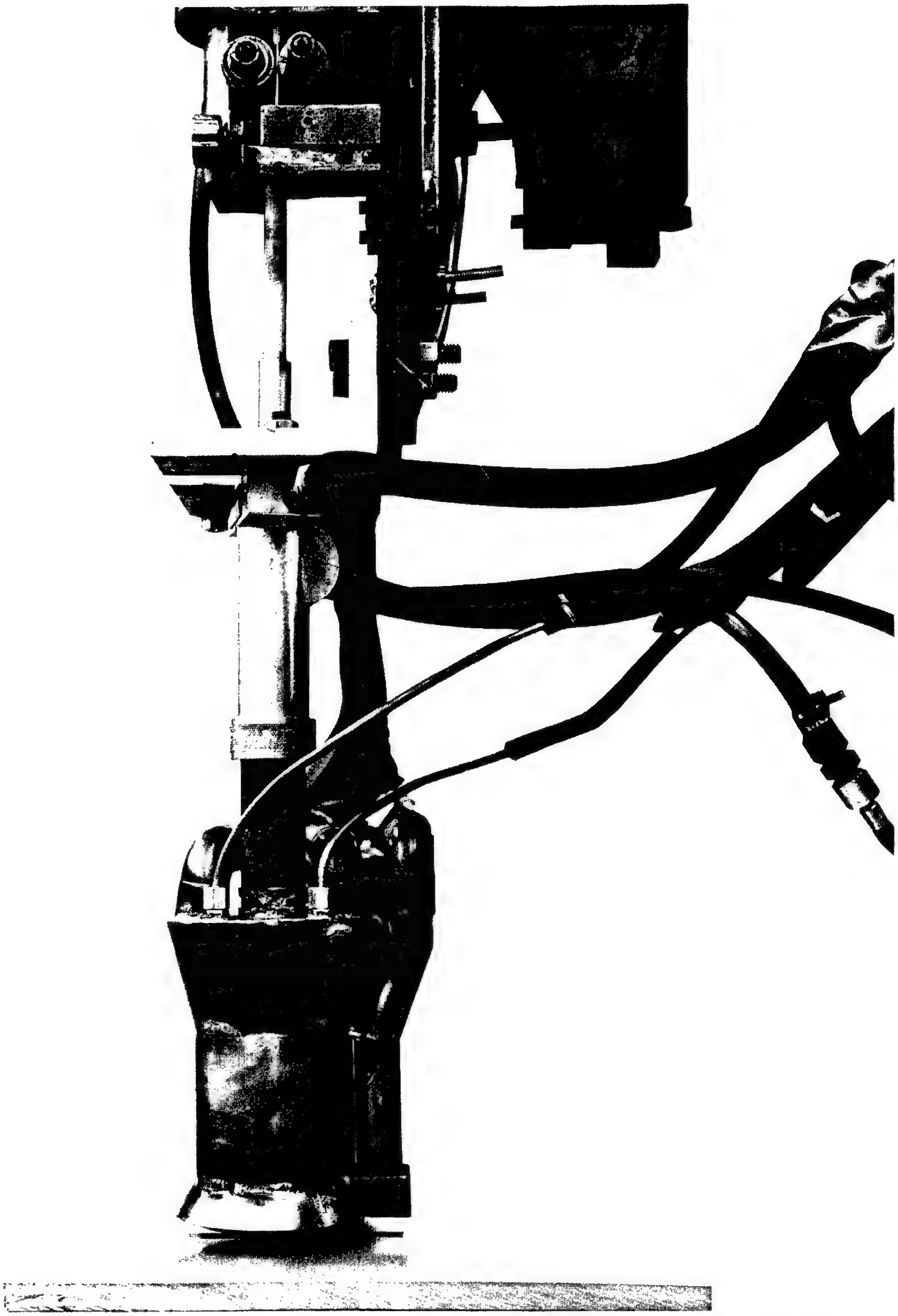


Figure 21.—Side view showing special welding nozzle mounted on machine barrel welding gun.

Fiber Optics

Close Observation of Welding Arc in Restricted Areas is Permitted by Use of Fiber Optics

The success of any fusion welding operation depends greatly upon close observation in the arc vicinity during the process. In this area, qualified technicians can readily detect any erratic action detrimental to quality. However, massive structures, as well as unique fabricating techniques used in modern missile systems, have made weld monitoring increasingly difficult. Often, design requirements or tooling provide only limited access and prevent technicians, equipped with the conventional welder's shield, from properly observing the welding process. As a result, Marshall Space Flight Center engineers have investigated the fiber optic technique and are currently utilizing its principle for close observation of the work in the vacuum chamber during electron beam welding.

The fiber optic technique consists of transmitting light through long, thin, flexible fibers of glass, plastic, or other material. These fibers are wound into flexible bundles and encased in a flexible protective sheath. The light transmitting ability of fiber optic cables is very good considering the fact that the light waves are guided through solid materials several feet long. Fiber optic bundles transmit color and can be mounted in pairs to transmit a stereo image for greater depth perception. While conventional optics could be employed in most cases by using the periscope principle, such a means of viewing is usually very fixed and must be carefully engineered for each installation. On the other hand, fiber optics, being very flexible, can be installed and re-used with only a minimum of engineering time. Therefore, the fiber optic method has great potential as an aid to research and development. The experimental unit shown in figure 22 consists of a flexible cable containing approximately 500,000 glass fibers. It has a focusing lens at one end and a binocular eyepiece at the other. One end is mounted near the welding torch at an angle that will permit optimum viewing. The technician can now monitor the weld unhindered by any obstructions.

The fiber optic system has proven to be extremely useful because of its flexibility and its color transmitting ability, and because it provides a means for the technician to see through the welding arc into the molten area. It has image transmission capabilities similar to those of straight optics but with considerable physical flexibility. An interesting possibility exists that fiber optics could be used to guide a picture image into a television camera and magnify the image on a TV screen.

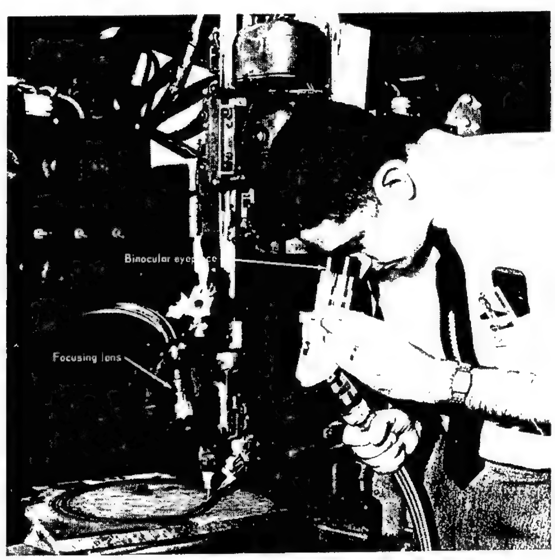


Figure 22.—**Fiber optic system used in close observation of welding arcs.**

Non-Free-Wheeling Thyratron-Type Motor Governor

Improved System Provides Needed Control in Motor Speed Shifts During Operation

Fusion welding to rigid specifications, as mandatory in space launch vehicle fabrication, necessitates extremely accurate control of the process. The automatic equipment used must respond rapidly to compensate for the many variables encountered. Consequently, this type of equipment must have an electrical system in which motor speeds can be varied precisely and rapidly during operation. However, conventional motor control systems were found to be inadequate and particularly deficient in achieving controlled deceleration to a lower speed. During such shifts of speed, there is a tendency for the motor to coast or free wheel for a period before it stabilizes at the lower level. To overcome this deficiency particularly, Marshall engineers developed an improved electronic motor control system that eliminates coasting or free wheeling during controlled deceleration. The improved motor control system is applicable not only to automatic fusion welding equipment, but also to the many other applications where motor speeds must be accelerated and decelerated during operation.

It should be pointed out that controlled deceleration is inherent in Amplidyne (trade name) and similar systems, and in at least one exotic electronic system. The system herein described is valuable when existing conventional systems must be modified and where cost is a prime factor.

Persons familiar with thyratron-type servo systems will recognize the system shown in figure 23 as one of a variety used to perform tasks in which a d.c. motor is employed to drive a mechanism to correct an error in position, voltage, or the like. An example of such a correction is the adjustment of weld torch distance from the work to maintain a preset voltage. The weld voltage is continually balanced against a reference voltage. The difference would be impressed across a–b and would vary in magnitude and polarity.

Assuming error voltage with polarity as shown, thyratron A would fire, causing half-wave rectified current to be supplied by transformer secondary winding TR1S1 to the armature. Error voltage of the opposite polarity would cause thyratron B to fire, providing current of opposite polarity to the motor, causing it to turn in the opposite direction.

If a speed potentiometer were substituted for the error voltage (fig. 24), the system would operate as a simple thyratron governor. The grid voltage of thyratron A is made up of half the total back EMF, the hold-off bias battery, half the set reference, and the a.c. bias. At constant speed, these values add up to approximately zero volts during the positive half cycle.

Meanwhile, the steady voltage across b–c and the voltage across g–h (proportional to speed), in conjunction with a–c bias and hold-off bias, would tend to maintain the grid of thyratron B negative in inverse proportion to the speed. The tachometer (driven by the motor), with adjusting resistor as shown, would tend to cause the grid to go positive in proportion to speed. This is adjusted so that thyratron B is on the verge of firing on the off half cycle.

Thus, when the reference voltage setting is

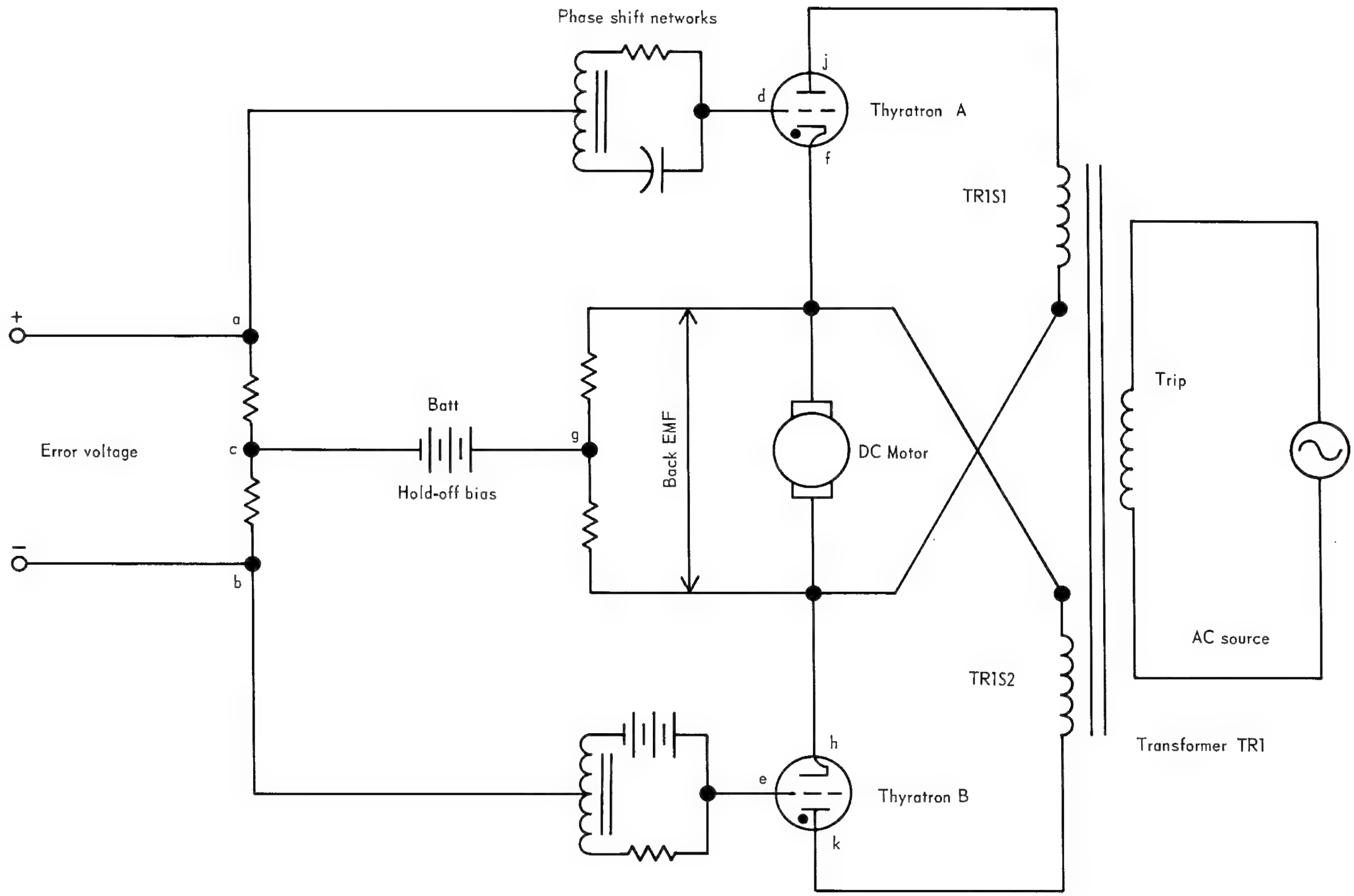


Figure 23.—**Simplified direct-current servo-amplifier with thyratrons.**

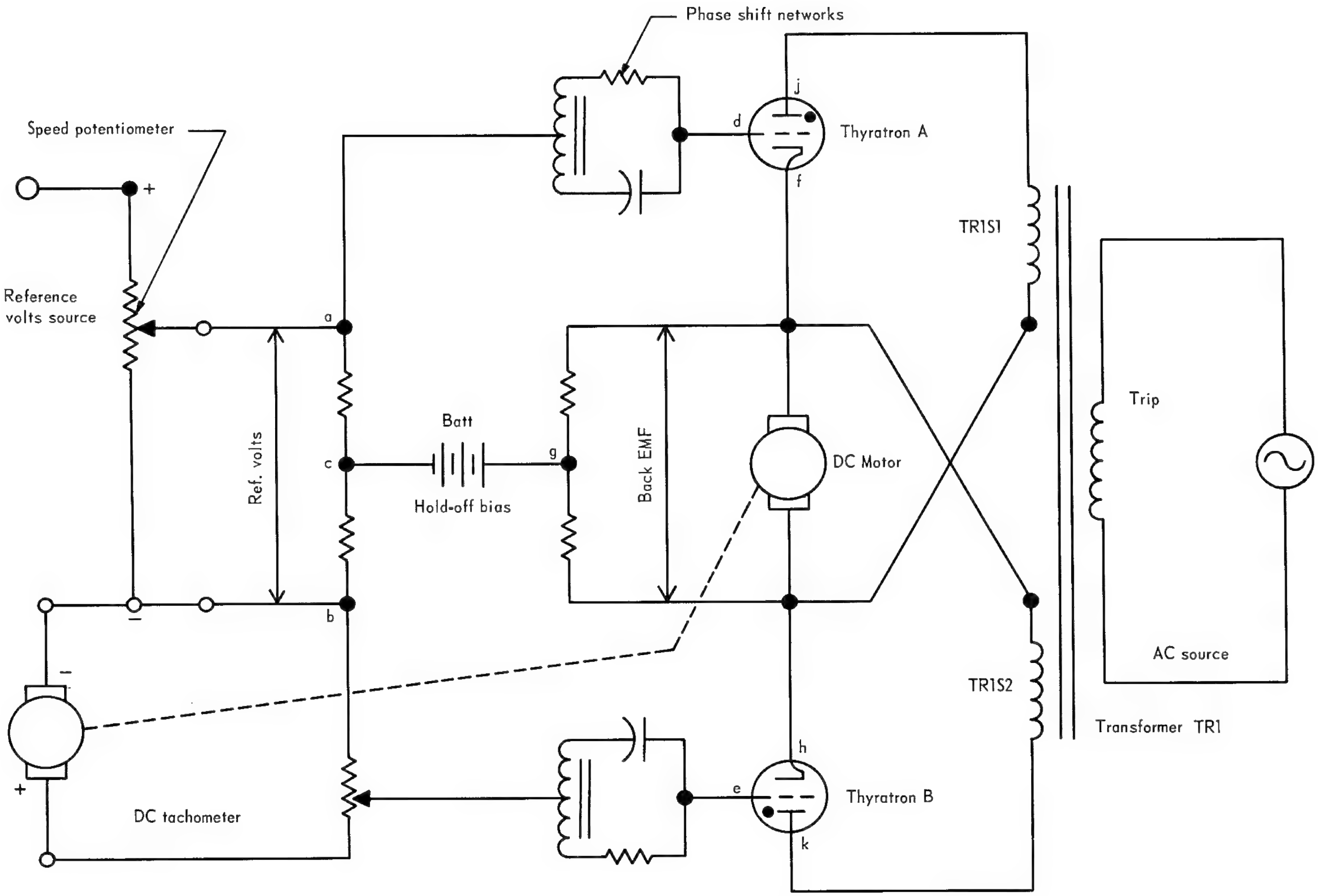


Figure 24.—**Circuit of figure 23 modified for non-free-wheeling.**

reduced to effectively reduce the voltage across a–c and c–b, two things happen:

(1) The reference voltage bias on thyratron A causes the grid to be more negative, and it cannot fire.

(2) The change in the part of the reference voltage across c-d is of such polarity and magnitude as to cause the grid of thyratron B to fire. This causes a flow of current of opposite polarity in the armature. Its speed is therefore reduced.

The braking force is roughly proportional to the amount of change. When the new set speed is reached, thyratron A resumes its normal functions and thyratron B becomes idle.

This circuit also corrects for conditions of overhauling load.

Magnetic Field Effects on a Direct-Current Welding Arc

Adverse Effects on Welds Shown in Test Series

Arc stability refers to the tendency of the arc to burn steadily in spite of the constantly changing conditions encountered during the welding operation. This tendency implies a uniform flow of heat to the work together with a steady rate of metal deposition in the face of transient forces tending to alter circuit conditions, either to extinguish the arc or to deflect it.

Because the conditions which affect the forces acting upon the arc vary greatly, it is impossible to make general recommendations for reducing or controlling all of these forces. However, one of the causes of arc instability may be attributed to the magnetic forces acting upon the arc. This condition is a result of the magnetic field induced by and surrounding the path of the welding current. The distortion of this magnetic field can be induced by the presence of external magnetic forces or materials placed in the arc vicinity.

To determine more accurately the effects of external magnetic forces acting upon a d.c. welding arc, Marshall Space Flight Center engineers conducted various investigations. The results obtained, as shown in the various illustrations, clearly indicate that no external magnetic fields of any appreciable magnitude can be tolerated near the welding arc. It has been determined that even 20 gauss can cause lack of penetration.

Figure 25 shows a mechanized d.c. gas tungsten-arc (TIG) welding unit with a single plate of aluminum alloy plate stock positioned for fusion welding. A "C" shaped permanent magnet, also shown in position, was used to provide an external magnetic field.

In order that the field strength at various points could be determined, the magnet was placed on a ½-inch grid scribed on the test panels, as illustrated in figure 26, and the magnetic field was measured with a Loren Flux Meter. Field strength, in gauss, is also shown in figure 27.

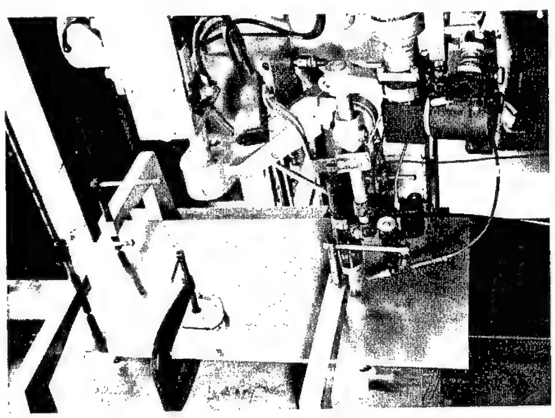


Figure 25.—**Permanent magnet in position for start of field effects test.**

Figure 27 shows the top bead on a ¼-inch panel. The weld bead as shown is relatively undisturbed. However, there is considerable loss of penetration at the root of the weld as shown in figure 28. This condition, directly related to

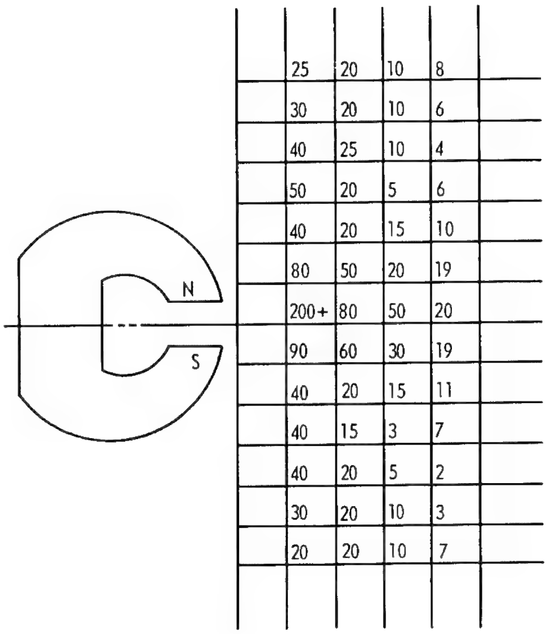


Figure 26.—Magnetic field strength in gausses at varying distances from magnet, ½-inch grid pattern.

the magnitude of the external magnetic field, is particularly noticeable at the 1-inch distance. Once penetration was lost, it was not fully recovered even when the magnetic field fell to almost zero. The weld beads shown at the 1.5-inch and 2-inch distances were welded with a higher current than necessary, thus enabling the arc to retain penetration. Figure 29 shows the macro specimens prepared from the weldment, and further illustrates the loss of penetration at the various distances from the magnetic field.

Since the force on the arc is directly proportional to the current flowing in the arc, weld bead disturbances are greater when welding increases thicknesses of material. Welds made in 1-inch thick panels showed weld bead disturbances at the 2-inch distance, where the field intensity was only 20 gauss.

Figure 27.—Effect of magnetic field on face of weld in ¼-inch 2219–T87 aluminum alloy.

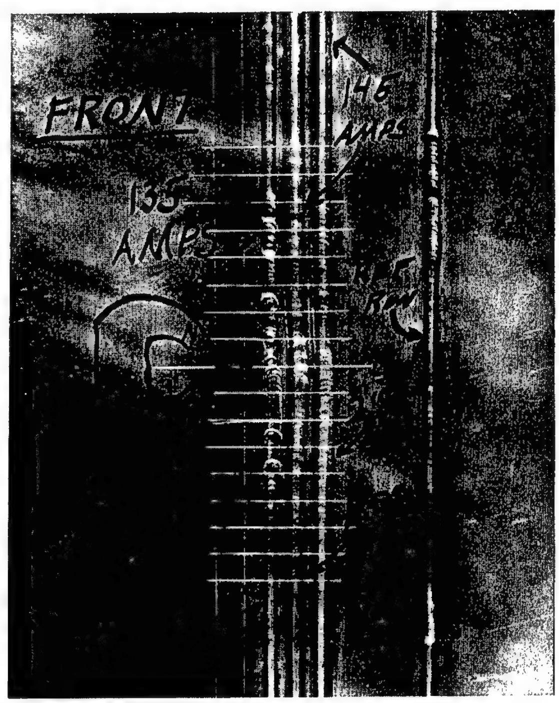


Figure 28.—Effect of magnetic field on root of weld in ¼-inch 2219–T87 aluminum weld.

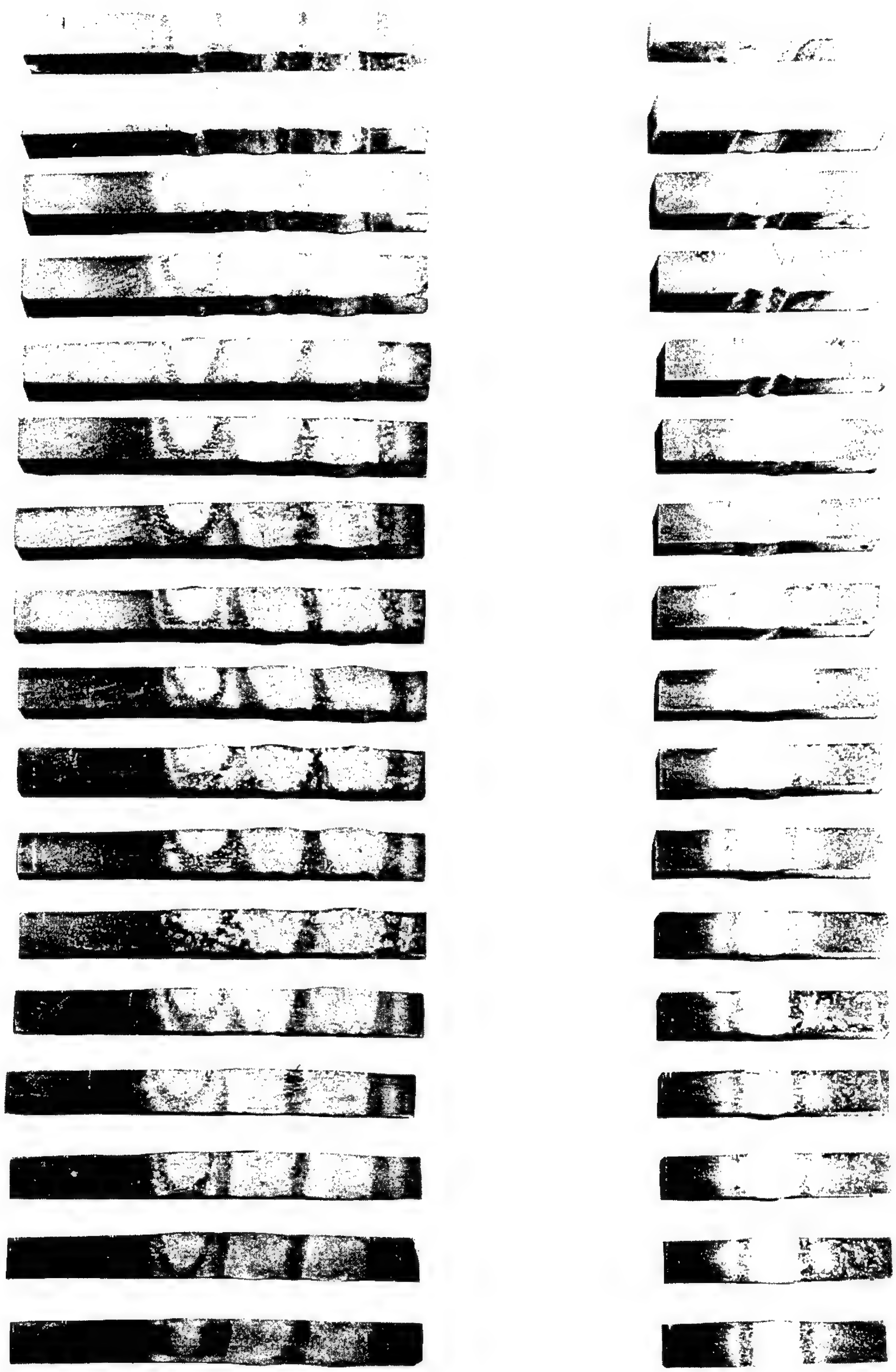


Figure 29.—Macro sections showing effect of magnetic field on root of weld at ½-inch intervals in ¼-inch 2219–T87 aluminum alloy.

Economy Automation for Welding of Space Vehicles

Improves Equipment Utilization and Reduces Investment

Automation is being applied to welding at Marshall Space Flight Center in an effort to reduce the number of special purpose fixtures required for a given program. In essence, if one simple boom manipulator can be used in conjunction with simple holding fixtures to weld pieces of various contours and shapes, equipment utilization can be improved and the investment in plant and equipment greatly reduced.

The system shown in figure 30 is designed for that purpose. The boom manipulator and the welding system are essentially conventional. The equipment is programmed by means of inexpensive function generators, figure 31, which have certain advantages over more sophisticated automation. Significantly, the programs for voltage, current, wire feed, torch angle, and speed may be determined by an operator on a specific work piece and may be quickly changed between successive test runs. There is no intermediate step such as tape punching.

Figure 32 illustrates the functioning of the system for torch angle θ, position, and linear speed.

Equal lengths are laid out on the weldment and points are marked. Each point corresponds to a line on the function generators. The head is jogged to point 1 and the torch angle is jogged as desired. The function generators for x position, y position, and θ are adjusted on line 1 so that the servo system is in balance, as indicated by a null on a meter in each case. This establishes the program for point 1. The same is done for point 2, and so on.

The function is such that, on welding, the boom will be extended x_1 inches and upward y_1 inches to reach point 2 in a finite length of time. Thus, the programmed travel is along h_1, the hypotenuse of the triangle. Proximity control on the torch insures that the torch follows the contour. Also, the torch attitude θ_1 changes linearly to θ_2 in that same length of time.

Since all time intervals are equal, and the linear distances between set points are also equal, torch travel speed with respect to work is constant. Travel speed is established by setting the interpolator drive speed to run through the program for a finite length of weld in a finite length of time.

Correspondingly, current and voltage may be made to change linearly between set points. Travel speed may be varied by changing the length between the points on the contour. While not adaptable to all applications, the system is quite versatile and may lead to considerable savings in time and money in future programs.

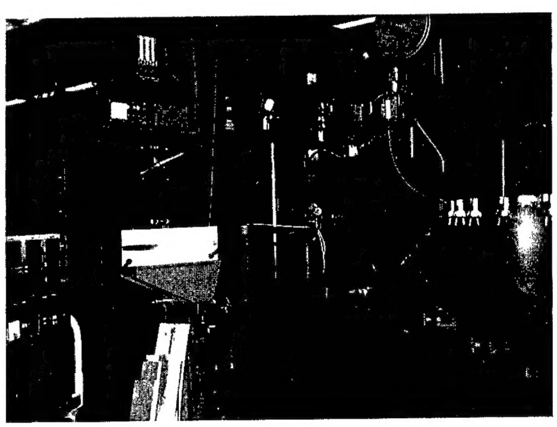


Figure 30.—Typical high performance welding system for use on latest space launch vehicles.

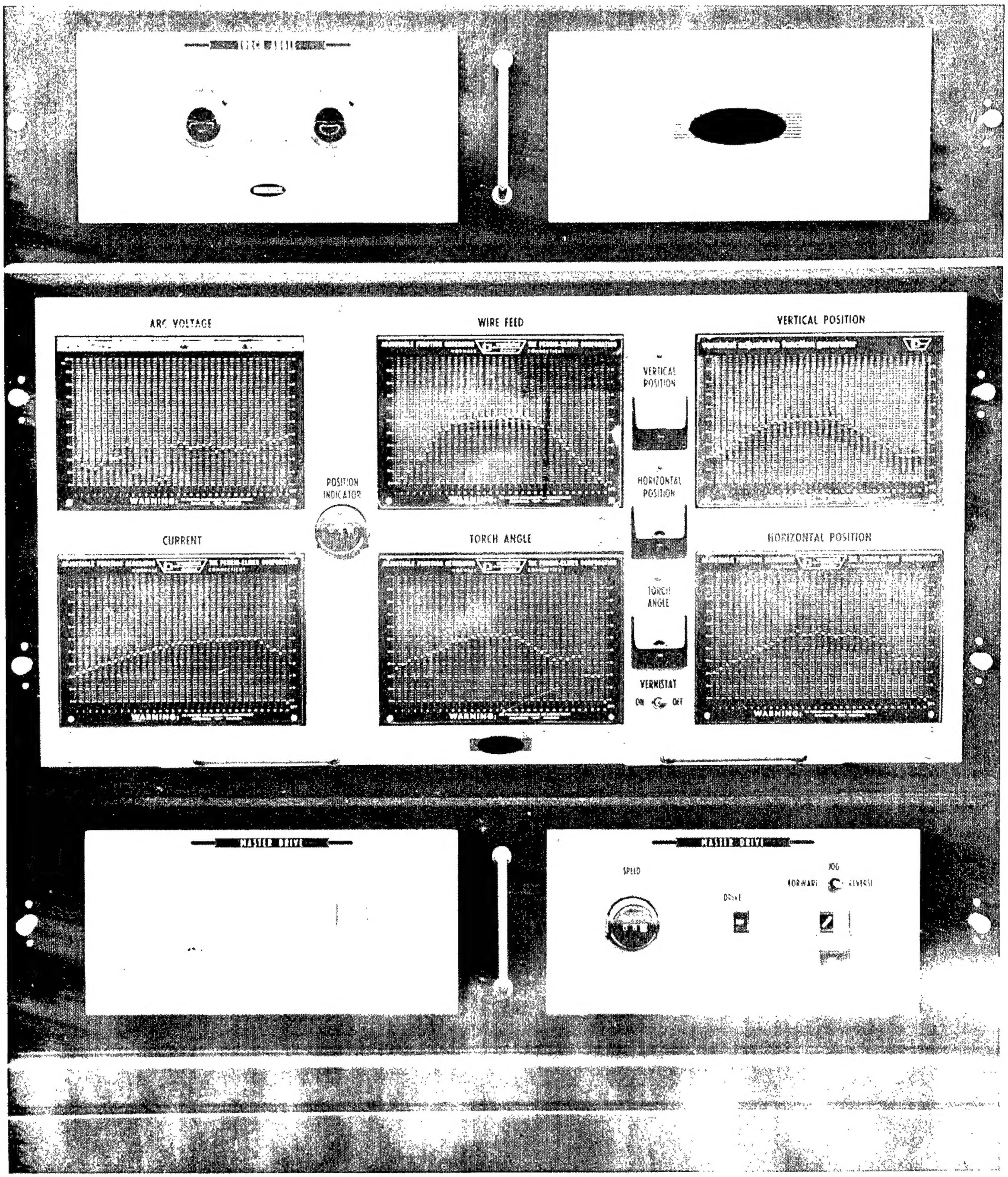


Figure 31.—Welding system function generator console and control panel.

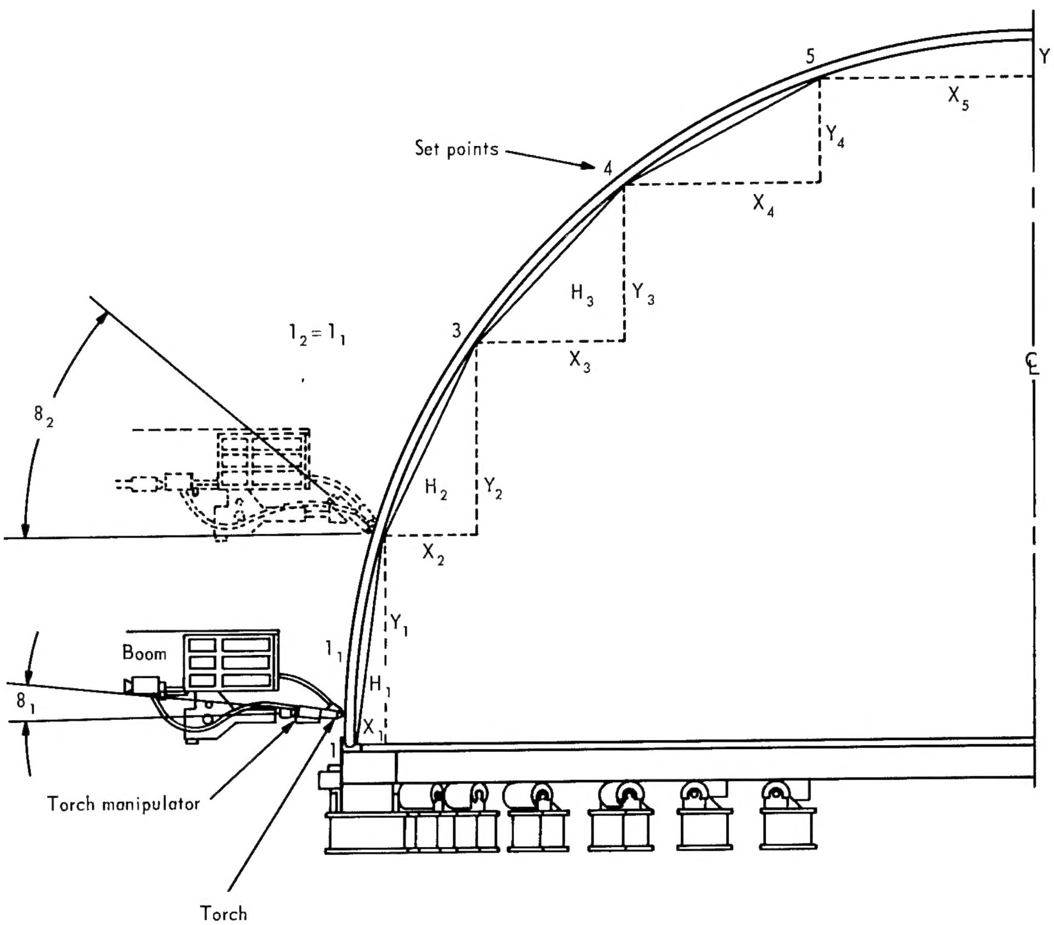


Figure 32.—Typical operating cycle of a function generator programmed welding system.

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